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DIGITAL PROCESSING OF WEATHER RADAR DATA AT THE DEPARTMENT OF METEOROLOGY, UNIVERSITY OF HELSINKI

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Abstract

The paper describes a solution for weather radar data processing problem with the aid of a general purpose digital multi-range-bin integrator. The integrator has 200 range bins. Binwidth is adjustable from the minimum of 375 m upwards and integration can be performed over 1, 2, 4, etc. up to 512 radar sweeps. By means of an external sampling control facility an analysis of signal fluctuations is possible.

1. *Introduction*

During the progress of radar meteorology, many kind of signal processing devices have been developed for weather radars. This was done because the amount of information obtainable from radar is very large and the flow of data is rapid. Collection of that information is difficult and impractical without some means which reduces the data flow rate but not the amount of information we are interested in.

The radar echo from precipitation fluctuates from pulse to pulse about its mean value, which is proportional to the radar reflectivity factor Z of the scatterers [3]. Because Z in turn is proportional to the rainfall rate and liquid water content, we are most often interested in Z and thus in the mean echo power. Therefore we need an equipment, which takes an average of backscattered power over sufficient number of radar pulses at a number of discreet points along the radar beam.

On the other hand, pulse to pulse fluctuations of radar echo are associated with the relative radial shuffling velocities of precipitation particles in the pulse volume. Thus the rate and other characteristics of fluctuations provide some information on the nature of the phenomenon we are looking with radar. For that reason our equipment should be able to collect and store data from individual, successive radar returns from any range desired.

Finally, the processing and recording device should be fast enough in order to prevent any loss of data flowing rapidly from the radar. Output must be in digital form in order to allow an easy further processing of data with computer or transmission of data via telecommunication lines.

That kind of problems have been tackled among others by LEHRMITTE and KESSLER [2], MITCHELL *et al.* [4], and SCHAFFNER [5]. The device of LEHRMITTE and KESSLER is an analog, multi-range-bin integrator. This means that the average echo power at some given range is obtained by summing the signal voltages, corresponding to that range, in analog form during sufficient number of successive radar pulses (range-bin ~ voltage capasitor). The number of range-bins used has been 100—200, which gives a rather good extent in range. This kind of equipment is best suitable for analog type of display (radar CRT) and additional devices are needed for digital output. Further, it seems in the authors' opinion that it is not possible to study, pulse to pulse fluctuations of a radar signal with an analog integrator, because the sampling time for one particular point is rather long (order of several microseconds) and fluctuations of weather echo are more rapid. Moreover, such a long sampling time per point provides a better estimate of the average echo power, because more independent data could be achieved by averaging over more than one pulse length besides the normal sweep to sweep averaging.

MITCHELL *et al.* [4] constructed a digital, multi-range-bin integrator. The most important difference to the device of LEHRMITTE and KESSLER is, that every sample of radar video signal is very short in time (50 nanosec) and the voltage is immediately converted into digital form by means of a 6-bit analog to digital converter. Resulting binary number is then added to the partial sum previously accumulated in the corresponding range bin. There are 256 range bins in the static shift register memory, each bin with 12-bit word size. As an advantage of a digital integrator its flexibility can be considered: many kind of digital data-logging devices can easyly be used with it.

SCHAFFNER's processing system [5], called CPL-system, differs considerably from any earlier radar processor. The philosophy of the CPL-system is based on the theory of »Finite State machine» and »automata», as they are called in logics and computer sciences. Schaffner's CPL processor is some kind of special purpose computer with an own programming language and its great advantage is its flexibility in respect to purpose of use. It is possible, with the aid of the CPL-system, to perform much more various functions (including averaging and analysis of fluctuations) than with earlier multi-range-bin integrators.

However, all present radar processors are »hand made» devices designed specially for some particular radar set. To plan and carry out such a processor is expensive and requires engineering. Another approach to the radar data processing problem is the use of some general purpose signal analyser. Such devices exist in a wide assortment on the market at reasonable prices. At the Department of Meteorology, University of Helsinki, a signal averager DL102S (by Data Laboratories Ltd) has been used with some slight modifications.

2. *Description of the system*

In principle, the DL102S is a digital multi-range-bin integrator like that device reported by MITCHELL *et al.* It uses the totalising multi-sweep method of averaging. During each sweep initiated by radar trigger, the waveform under investigation is sampled at a number of equally spaced discreet points. Each point is digitised and summed in the memory with corresponding samples from further sweeps. As a preset number of sweeps has been reached, there are in any word of the memory the sum of values sampled at some fixed point of sweeps corresponding to the time difference between the radar trigger and the

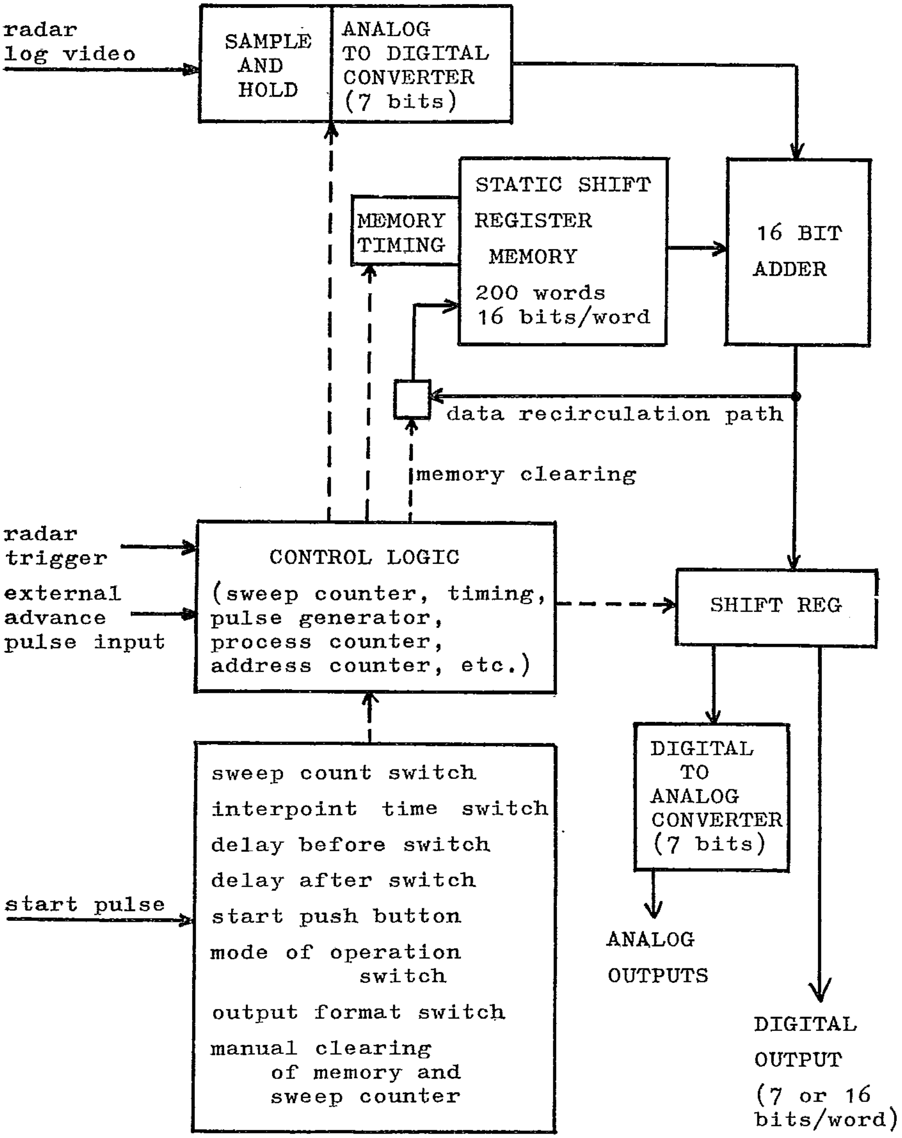

Fig. 1. Simplified block diagram of the averager.

sampling instant of the word in question. The contents of these words, divided by the number of sweeps sampled, yields the average signal.

2.1 Digitalizing and averaging

Fig. 1 shows a simplified block diagram of the averager. Sampling of radar video signal is accomplished with a sample and hold unit, which takes a sample of signal voltage during 20 nsec and keeps it constant during analog to digital conversion. The sample and hold unit was not a standard component in our averager. Because the analog to digital converter is of »successive approximation» type with 2 μsec's conversion time, it is essential to use this kind of circuit before the converter. Without a sample and hold unit the resulting binary number do not represent accurately the signal voltage, because the signal can change rather much during the conversion time.

The analog to digital converter converts the sampled signal to a 7-bit binary word. Thus, the resolution is 1/128 of the full scale of the input or 1/128 of 2 V (from -1 V to $+1$ V). Because the maximum dynamic range of the weather echoes we are interested in is typically 80 db, the resolution one can achieve with a 7-bit converter is on the average 0.62 db in received power. Signals above $+1$ V or below -1 V are clipped to $+1$ V or -1 V respectively before conversion. So an »owerflow» at the analog to digital converter is impossible.

After analog to digital conversion the resulting 7-bit binary number is added to the contents of the corresponding range-bin in the memory of the averager by means of a 16-bit binary adder. Data storage in the averager is accomplished by circulating the digitised information in a static shift register memory. The store size is 200 words (range-bins), each with a 16-bit word size. This word size together with 7-bit analog to digital conversion implies, that up to 512 sweeps could be summed in the memory without any danger of overflow. The number of sweeps, over which the average is taken, is controlled by the sweep counter. 1 to 16384 sweeps can be preset by a switch in binary increments. (Sweepcounts greater than 512 are useful only if we know, that the signal is always considerably below $+1$ V).

Sampling of the sweep is initiated by the radar trigger. The time between successive samples of a particular sweep is determined either by an internal timing pulse generator or by an external pulse train. In the former method one can choose interpoint times 2.5, 5, 10, 25 etc. up to 50000 μsec corresponding to the range resolution of 375, 750, 1500, 3750 etc. m/point respectively. With the maximum resolution and 200 range bins the total processing range of the averager is 75 km. With the resolution 3750 m/point the range is 750 km. Thus, in normal use, only four fastest sampling speeds are useful.

With the external sampling advance facility one can determine sampling instants arbitrarily by an external pulse train. Minimum interpoint time in this mode of operation is 5 μsec. As we shall see later, the external advance facility provides the means, by which one can perform an analysis of signal fluctuations.

In addition to these sweep speed controlling facilities, there are two build-in incremental crystal delays, which are useful in optimization of measurement requirements. The preanalysis delay enables the start of the sampling of the sweep to be delayed with respect to the trigger. This makes it possible to leave out of analysis for instance some ground echoes near the radar. The post-analysis delay allows for the setting of a fixed period after each sweep during which all trigger pulses from radar are neglected. With this facility one can vary the amount of independence between sweeps by taking for example only every second radar sweep into the averager. This method is not a very practical one in normal averaging. The same (or a slightly better) result could be achieved simply by doubling the sweep count. But if we are studying signal fluctuations and the time needed to independence, it may be useful to compare averages of every sweep, every second sweep, every third sweep etc.

2.2 Output

Both digital and analog outputs belong as standards to the averager. There are two different possibilities to connect an analog output device to the averager. First, the store contents may be displayed as a series of 200 points on an oscilloscope, each point representing in analogue form the binary number contained in a particular store location. The 16-bit number in each location is displayed to 7 bits resolution. Because of the rapidly circulating structure of the memory, display is possible even during the averaging process. This feature could provide a possibility to feed the averaged information back to the radar CRT for real time inspection of averaged echoes. However, this possibility has not yet been realized in the present configuration of the processing system. Another, much slower analog output is provided for xy-plotters or chart recorders.

For digital output devices, 16 data lines and necessary control lines are available. The data can be read out serially (serial by word, parallel by bit) from the memory of the averager at practically any desired rate. This permits a wide assortment of digital data logging devices, including paper tape punches, magnetic tape units and computers, to be used. As the amount of data obtainable with radar is typically very large, the best choice would be a computer or a high speed magnetic tape. Since these alternatives are rather expensive, a medium speed paper tape punch has been used as an output device in the first experiments.

The punch used is able to punch up to 110 character/sec onto 1 inch standard eight-channel paper tape. Four various output formats are used. First, all 200 words can be punched with 16-bit accuracy. In this format every word is punched as two 8-bit binary character, first of them representing the eight most significant bits of the word and the second the remaindering eight bits of the word. Secondly, all 200 words can be punched with 7-bit accuracy, the 7 bits determined by the number of sweeps averaged (same bits as used in the analog display). This output format is in most cases accurate enough. If we for instance take an average over 32 sweeps, the resulting word size is 12 bits. Thus the resolution has apparently increased from 0.6 db (1 sweep) to 0.02 db (32 sweeps) assuming that the digitizing range corresponds to the dynamic range of 80 db of weather echoes. If we keep in mind, that with 32 independent samples the standard deviation σ_m for the estimate of the mean is $\sigma_m = 5.57/\sqrt{32} \approx 1$ db (according to Lehrmitte and Kessler [2]) not very much could be gained by using the 16-bit output instead of the 7-bit output. On the contrary, with the 7-bit format, both the amount of output tape and the output time are decreased to a half of values needed for a 16-bit punching.

Two additional alternatives available for digital output are composed of either format described above by punching out only the 100 first words of the memory. In most cases, this method provides a sufficient extent in range.

With the 7-bit resolution the punching time for 100 words is about 1 sec, whereas for a 16-bit resolution and 100 words (or 7-bit resolution and 200 words) that time is about 2 sec. Maximum output time, 4 sec, is needed when punching 200 words with 16-bit accuracy.

Before each output process two »blanc» characters and a special character are punched. This provides a means by which the beginning of the punchout of an average is easy to identify. The special character is a binary 1, 3, 5 or 7 corresponding to one of the four output formats described above. In all formats, positive numbers are represented in pure binary form, whilst negative numbers are represented as their complement with respect to 2.

2.3 The present configuration of the processing system

Figs. 2 and 3 present the existing radar signal processing system at the Department of Meteorology, University of Helsinki. The radar video from the logarithmic amplifier of the receiver is fed to the averager trough an additional amplifier. The function of this amplifier is to adjust the raw log video best suitable to the input range (—1 V —+1 V) of the averager. By means of this amplifier one can take only a limited amplitude range of the video under investigation, if needed. Also the radar trigger is fed to the external trigger input of the averager. These are the only necessary connections needed for signal averaging.

An averaging process can be initiated either manually or with an external start pulse. Manual start is mainly used in system calibration

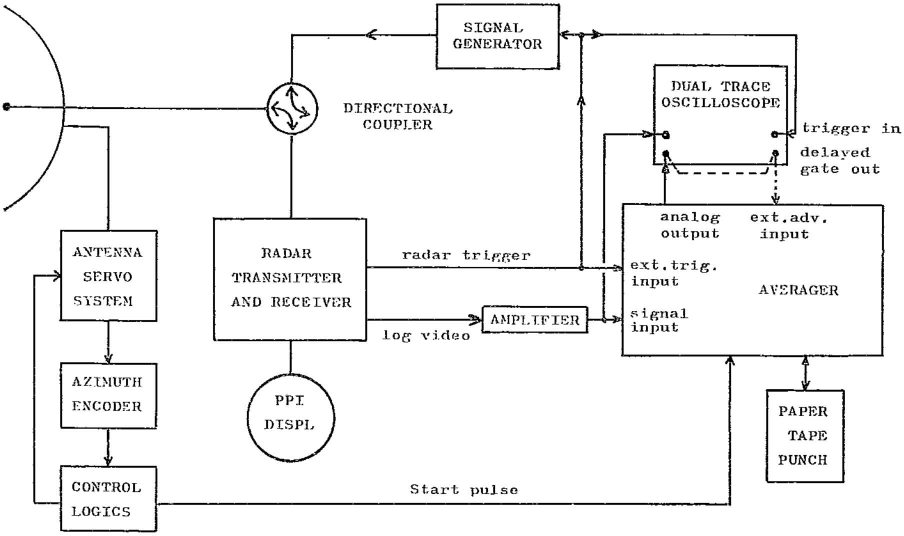

Fig. 2. Schematic block diagram of the weather radar signal processing system.

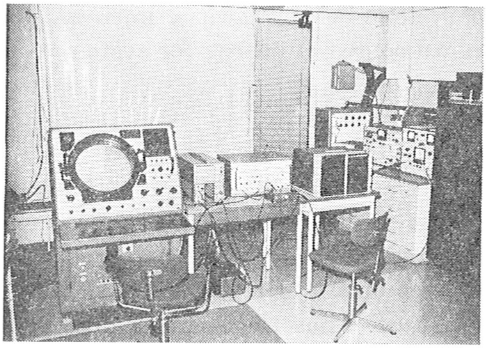

Fig. 3. Radar signal processing system. From the left: radar display unit, oscilloscope, signal averager and paper tape punch. Behind the punch the microwave signal generator and the transmitter/receiver cabin of the radar are seen.

and in some special measurements. In routine PPI-data collection start pulses are generated in the azimuth angle data presentation unit of the antenna at every second degree of azimuth. The rotation rate of the antenna is decreased to about 1/4 cycles/min in order that the punch had time to punch the data out before the next start pulse two degrees of azimuth later occurs. The punch is connected to the averager such a way that one can choose either manual or automatic mode of operation. In the automatic mode the operation is as follows: after a start command the averager takes an average over preset number of sweeps, then automatically punches the contents of the memory out and after punchout arms itself ready for the next averaging by clearing the memory and resetting the sweep counter. In the manual mode, both the commencement of output and the »arming» must be done manually.

An external oscilloscope serves as a display unit for monitoring both the video signal and the analog output of the averager. The time base (Tectronix 7B53AN) of the oscilloscope is also used as a delayed pulse generator for the external sampling speed control of the averager in the analysis of signal fluctuations. In this kind of operation it is possible to collect data from individual, successive radar returns from some fixed range and store it in successive words of the memory. This is achieved simply by employing the delayed radar trigger pulses to determine the sampling instants in the external sampling advance mode of operation. The amount of delay determines the distance, from where the samples are gathered.

To the entire system belongs also a microwave signal generator. It is used as a known source of energy for system calibrating purposes.

3. Some examples

Fig. 4 illustrates the effect of averaging fluctuating precipitation echoes. In all examples presented, the wavelenght of the radar is 3.2 cm, pulse length 3 μsec and the pulse repetition frequency 245 p/sec. The distance between range-bins is 375 m, which is 75 m less than a half of the pulse length used. Thus the samples in consecutive range-bins are nearly independent of each other. It is readily seen, how the waveform approaches the average as the number of sweeps averaged increases. After 256 sweeps not very much seems to be gained by increasing the sweep count. This is obvious because assuming 256 independent samples of logarithmic video, the standard deviation of the mean has the following value, $\sigma_m = 0.35$ db. Hence about 68 % of the estimates falls inside the ± 0.35 db error limits, which is the same order of magnitude as the resolution of the 7 bits displayed.

Fig. 6 depicts a computer processed PPI-picture recorded by means of the signal averaging system and Fig. 5 shows the corresponding situation photographed simultaneously from the radar PPI-scope. Originally, one complete digital PPI-picture is composed of 18000 7-bit point values. Radial distances between consecutive range-bins in this particular example are 1.5 km and 100 point averages over 64 sweeps are taken at every second degree of azimuth.

Because the data is quantized and recorded to 7 bits resolution, it is not necessary to apply a range correction of radar video in analog circuits of the radar. This correction is easy to perform later with the aid of a computer, as the data is processed. In so doing we do not miss weak echoes at shorter ranges, as may happen if the correction is done before quantizing by attenuating the echoes inversely proportional with respect to the square of the radar to target range.

Figs. 7 and 8 illustrate the possibilities of the averager in analysis of signal fluctuations. As stated earlier, with the external address advance facility one can collect 200 successive samples of the backscattered power from some particular range (one sample per word in the memory of the averager). From this kind of data one can determine for example experimental probability density of signal intensity. Also it is possible to calculate the difference between the true average power and that

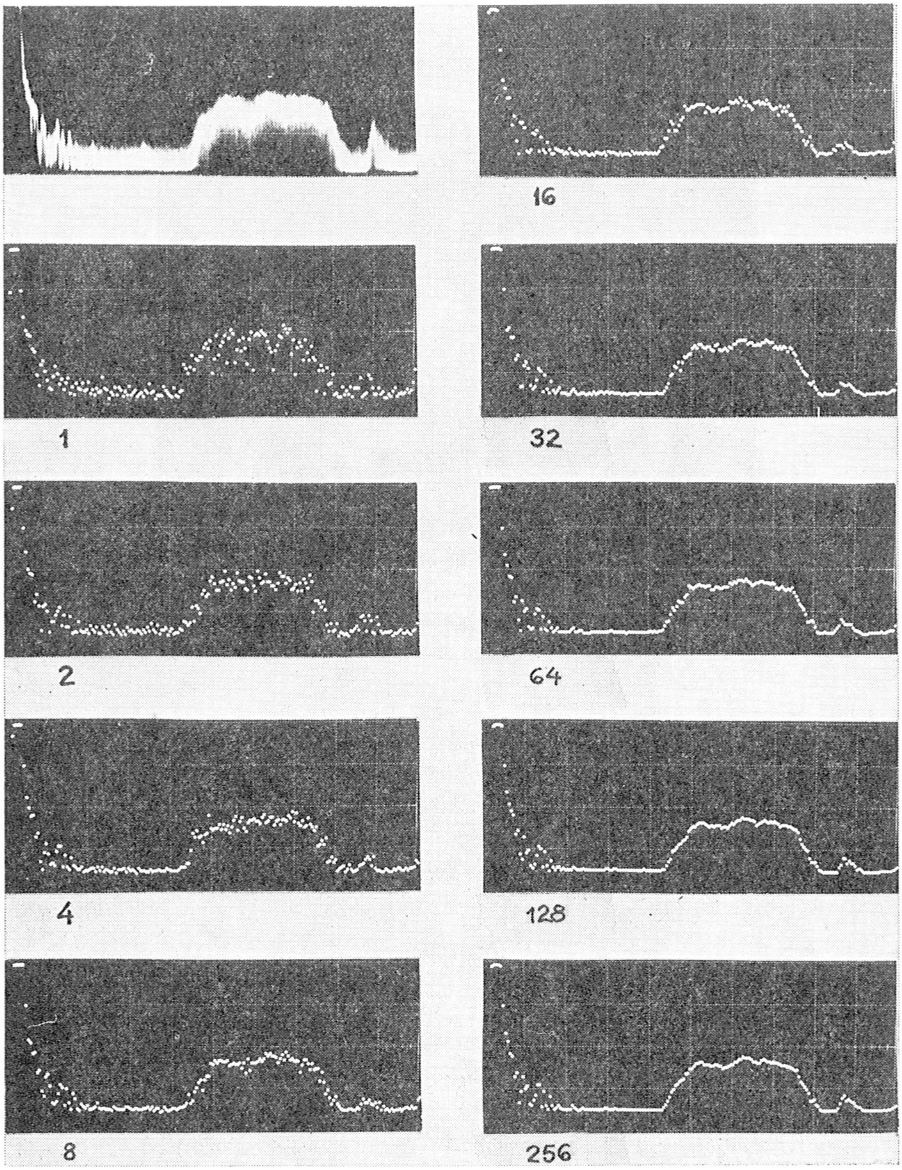

Fig. 4. Raw radar video on an A/R-scope (upper left picture, superposition of about 120 sweeps) and corresponding average waveform obtained after averaging over various numbers of sweeps (number of sweeps is indicated below each picture).

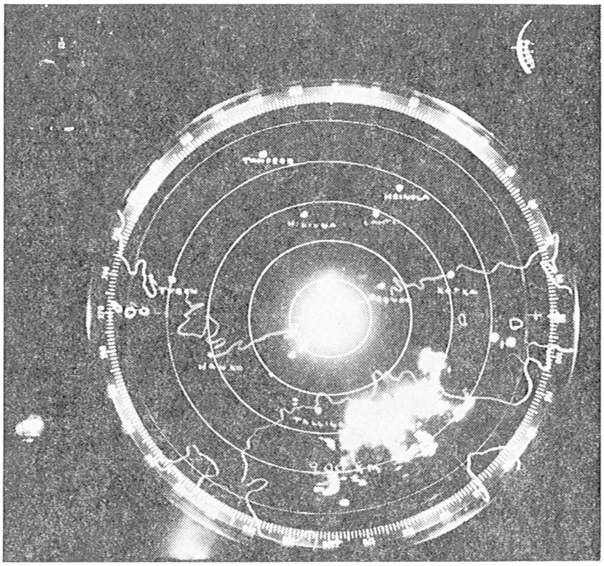

Fig. 5. Radar PPI-scope photographed simultaneously as the digital data shown in Fig. 6. is beign recorded. Range-rings are 40 km apart of each other. The digital data collection in this example is performed to the range of 150 km.

mean, which is obtained by averaging the logarithmic video of the radar. MARSHALL and HITSCHFELD [3] showed that this difference is 2.5 db in the case of pure logarithmic characteristics of the receiver output. However, in the real case, the radar transfer function is never exactly logarithmic. This causes deviations from the theoretical value of 2.5 db. Use of finite intensity intervals in quantizing may also lead to large errors in averaging [1], and last, differences occur if the probability density distribution of the fluctuating signal differs from the theoretical (Rayleich's) distribution.

Because the samples of consecutive radar pulses are in consecutive words of the memory of the averager, an autocorrelation analysis of the fluctuating signal seems to be possible. Unfortunately, there may be up to 2.5μ sec jitter between the receipt of a sampling command and the sampling itself (in the external advance mode). This results from the circulating structure of the static shift register memory. If the pulse length of the radar is 3 μsec, one can observe immediately, that consecutive samples may be totally independent of each other because they may be sampled from discreet contributing regions of

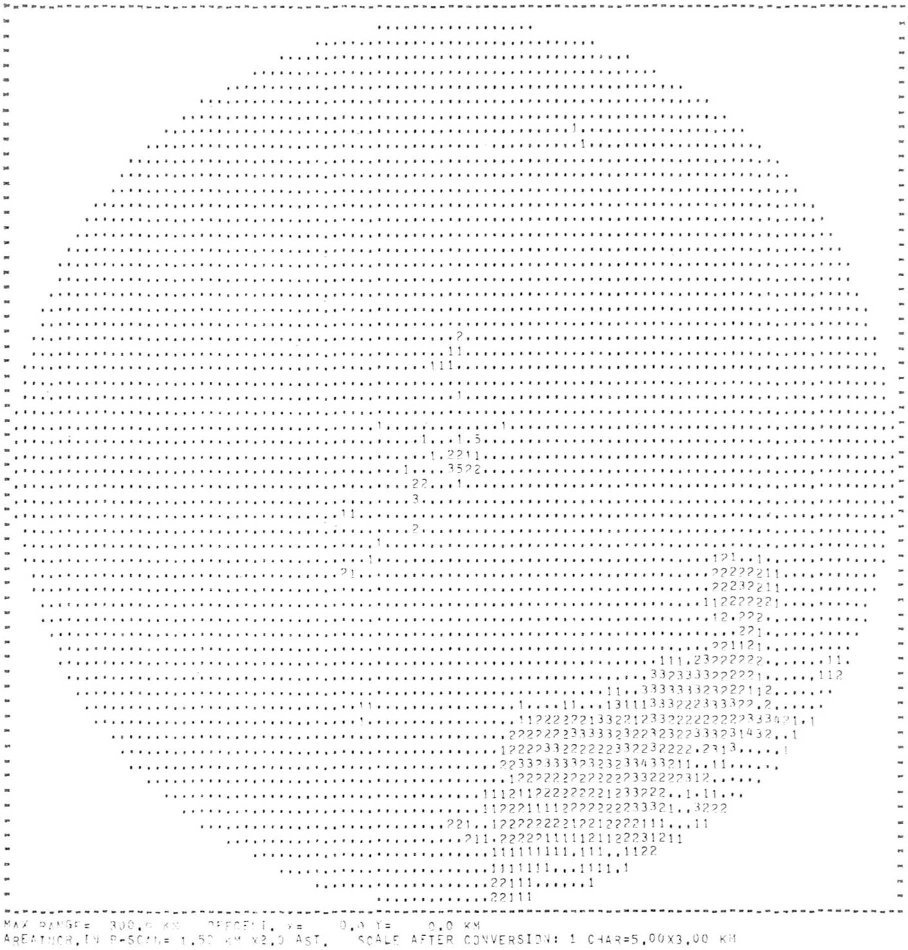

Fig. 6. A digital radar PPI-picture recorded simultaneously with the photograph shown in fig. 5. The distance from the center to the edge of the picture is 150 km. Integers are logarithms of radar reflectivity factor Z. Values of $Z < 10$ are not printed out in this picture.

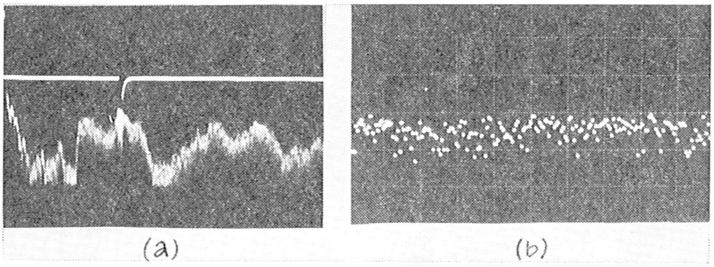

Fig. 7. (a) An A/R-scope photograph of a fluctuating weather echo (lower trace) and the external sampling pulse (upper trace) showing the point, from where the successive samples are gathered in the analysis of signal fluctuations. (b) The store contents of the averager displayed after collection of data from the point denoted in (a).

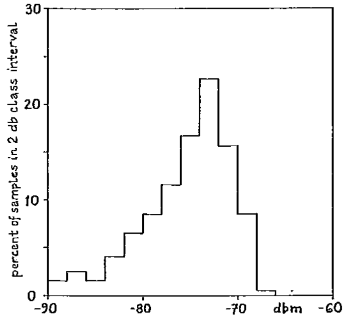

Fig. 8. Histogram showing the frequency distribution of signal intensity in 2 db intervals obtained from the same data as in fig. 7. The total amount of samples is 199. The true average power calculated from the data is —73.3 dbm and average power achieved by averaging the video is —75.2 dbm.

scatterers. However, work is going on to study the possibilities to minimize the jitter.

4. *Summary and conclusions*

A digital radar data processing system has been developed by using a general purpose signal averager. The advantage of the system lays in its flexibility with respect to both the radar and the data-logging device. The minimum necessary connections needed from the radar are the radar logarithmic video adjusted to the input range of the averager and the radar trigger. Further, with this averager it is possible to study pulse to pulse fluctuations of received power in some extent.

The most serious disadvantage of the present system is the unfeasibility of its output device, paper tape punch: the time needed for digitizing and punching one complete PPI-picture is about 4 min and one reel (1000 ft) of paper tape can accept only 6 pictures. This disadvantage can be avoided by using a faster and more reliable output device.

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